2.0 PROPOSED ACTION AND ALTERNATIVES EVALUATED

The 1995 Cassini EIS, released in July 1995, examined mission alternatives available at that time for accomplishing the mission objectives within a reasonable time frame, as well as the No-Action Alternative. In the course of developing the mission alternatives, three major mission components (launch vehicles, mission trajectories to Saturn, and spacecraft electrical power sources) were examined in detail (JPL 1993a, JPL 1993b, JPL 1994). These three mission components remain the principal factors influencing the development of feasible mission designs (mission alternatives) and are also the factors determining the potential environmental impacts associated with each mission alternative under normal (incident-free) and accident conditions. Updated information regarding the evaluations of these three components and their availability in determining the mission alternatives is provided in this section.

The 1995 Cassini EIS examined in detail the feasible components that combined to form those mission alternatives; the Proposed Action (a 1997 Titan IV [SRMU or SRM]/Centaur launch), a 1999 Mission Alternative (a dual shuttle launch), a 2001 Mission Alternative (a Titan IV [SRMU] launch) and the No Action Alternative. The 1999 Mission Alternative would have involved dual Shuttle launches in 1999, with on-orbit assembly of the spacecraft and a specially-designed and developed upper stage. The launch site for this alternative would have been either Launch Pad 39A or 39B located at Kennedy Space Center (KSC) in Florida. The 1999 Mission Alternative is no longer being considered because of the insufficient time to develop and test the special upper stage, and associated cost.

Of the alternatives examined in the 1995 Cassini EIS, only the following are currently available to NASA:

- <u>Proposed Action</u> - The Proposed Action and preferred alternative consists of completing preparations for and operating the Cassini mission to Saturn, with a launch during either the primary (October-mid November 1997), secondary (late November 1997-January 1998), or backup (March-April 1999) opportunities. The SRM-equipped Titan IV/Centaur launch vehicle option that was considered in the 1995 Cassini EIS is no longer available. The SRMU is now fully flight-certified for use on the Titan IV. The first Titan IV(SRMU) mission was successfully launched by the Air Force on February 23, 1997.

- <u>2001 Mission Alternative</u> - This mission alternative is to complete preparations for and operate the Cassini mission to Saturn in March 2001, or during the backup opportunity in May 2002. This alternative would utilize the Titan IV (SRMU)/Centaur launch vehicle.

- <u>No-Action Alternative</u> - Under the No-Action Alternative the mission would not be implemented.

A brief description of the Proposed Action is found in Section 2.1 of this SEIS. Changes in spacecraft design, the Earth swingby maneuver of the gravity-assist trajectory, and the range safety systems that have been made since completion of the 1995 Cassini EIS are highlighted.

Sections 2.2 and 2.3 of this SEIS provide brief additional details of the 2001 and No-Action Alternatives, respectively. The changes made in the spacecraft design, range safety system and Earth swingby maneuver noted for the Proposed Action also apply to the 2001 Mission Alternative. Additional details regarding the 2001 Mission and No-Action Alternatives can be found in Sections 2.4 and 2.5 of the 1995 Cassini EIS. For additional details of the Proposed Action, refer to Section 2.1 of the 1995 Cassini EIS.

2.1 DESCRIPTION OF THE PROPOSED ACTION

The following paragraphs summarize the basic elements of the Proposed Action that are pertinent to evaluating the results of the refined accident analyses and to comparing those results with the 1995 Cassini EIS analyses. Changes that have been made in the areas of range safety systems, spacecraft design, and in the design of the EGA trajectory are discussed where applicable.

2.1.1 Mission Design

The primary launch opportunity of the Proposed Action occurs within a 41-day launch period beginning October 6 and closing November 15, 1997 (JPL 1993a). Using the Titan IV (SRMU)/Centaur described in Section 2.1.6 of this Final SEIS, the spacecraft would be launched and injected into the 6.7-year VVEJGA interplanetary trajectory to Saturn, as shown in Figure 2-1.

After the spacecraft's launch and injection into the interplanetary trajectory in October 1997, it would swingby the planet Venus for the first time in April 1998, followed by a second Venus swingby in June 1999. The spacecraft would then fly on to Earth in slightly less than two months, where it would obtain its third planetary gravity-assist in August 1999. The spacecraft would obtain a fourth and final gravity-assist at Jupiter in December 2000, before proceeding to Saturn.

Cassini would arrive at Saturn in July 2004 and begin a four-year tour of the Saturnian system, after deploying the Huygens Probe on a trajectory for entry into Titan's atmosphere.

<u>Changes in Mission Design Since the 1995 Cassini EIS</u>: Two mission maneuvers have been altered. First, the swingby altitude for the Earth gravity assist maneuver has been increased from 500 km (310 miles) to 800 km (500 miles) or higher. Second, the last

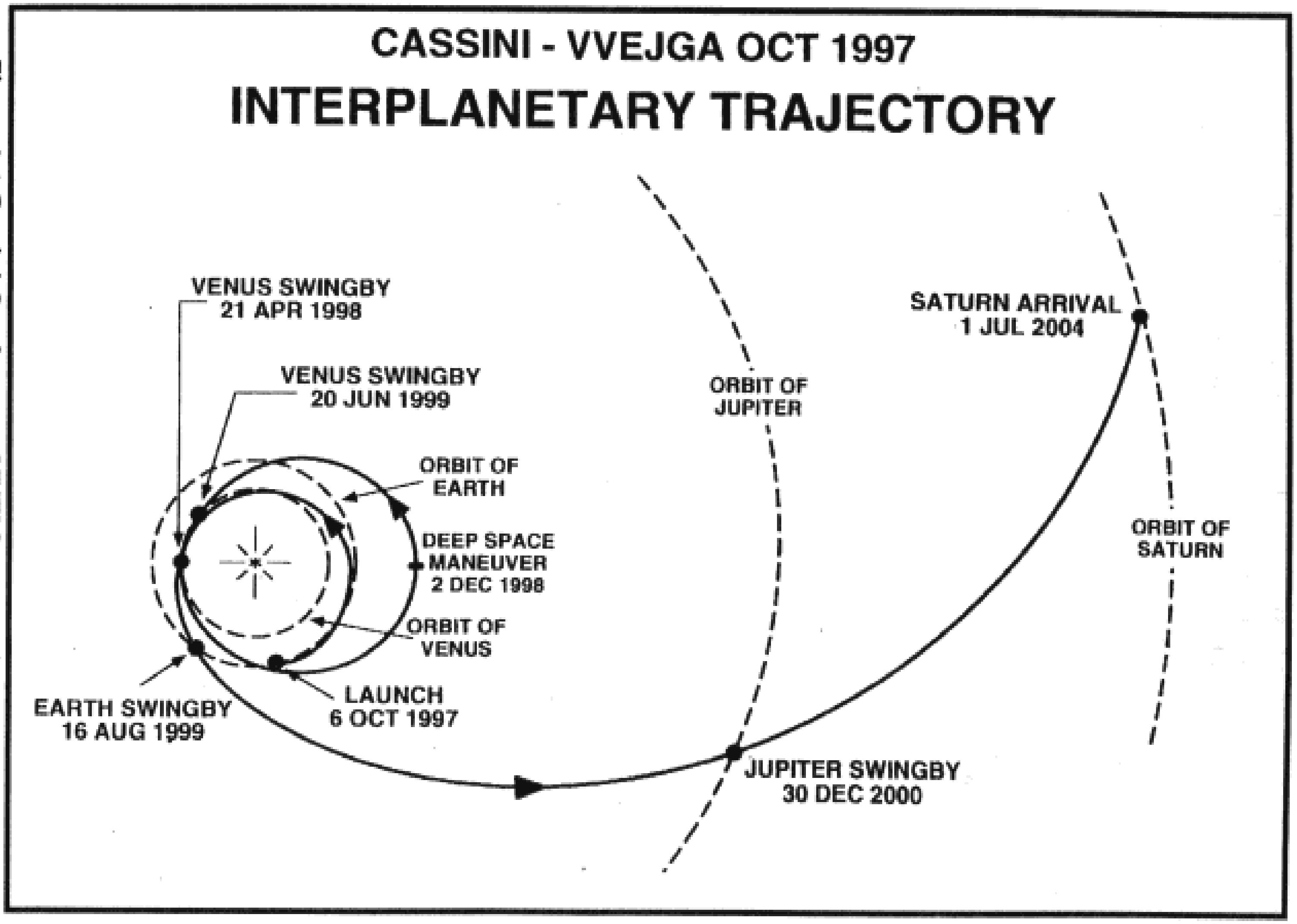

Figure 2-1 Cassini October 1997 VVEJGA Interplanetary Trajectory

trajectory correction before the Earth swingby has been delayed from ten days prior to swingby to seven days prior to swingby. This delay in the maneuver increases the biasing of the trajectory away from Earth during the period before the Earth swingby. Both of these changes work to keep the chances of an inadvertent Earth swingby reentry below one in one million.

2.1.2 Launch Opportunities

For the Proposed Action, the primary launch opportunity occurs during the 41-day period between October 6 and November 15, 1997. Problems with the launch vehicle or spacecraft or adverse weather conditions during this period could cause the loss of this primary launch opportunity.

Mission planners have identified secondary and backup launch opportunities from late November 1997, through early January 1998, and from mid-March to early April 1999, respectively, in the event such conditions arise. Both the secondary and backup opportunities would utilize a VEEGA trajectory to Saturn instead of the VVEJGA trajectory used with the primary launch opportunity.

Both the secondary and backup launch opportunities would have adequate allocations of propellant to meet the minimal science objectives. However, lower electrical power output available from the RTGs during the science portion of the mission due to the natural decay of the radioisotopes would result in fewer instruments being operated at a given time, or less engineering support given to some instruments (JPL 1993c). These mission constraints would reduce the science return from levels anticipated for the primary launch opportunity.

2.1.3 Spacecraft Description

The Cassini spacecraft, illustrated in Figure 2-2, is designed to be a three-axis stabilized probe-carrying orbiter for exploration of Saturn and its atmosphere, moons, rings and magnetosphere.

The components of the spacecraft relevant to an assessment of the potential for environmental impacts from the mission are the RTGs, RHUs, the propellants, and the propellant pressurant (helium). (RTGs and RHUs are addressed in Section 2.1.4 of this SEIS.) For propellants, Cassini would carry up to 132 kg (291 lb) of hydrazine for small maneuvers and attitude and articulation control, and about 3,000 kg (6,614 lb) of bipropellant (one tank each of monomethylhydrazine [MMH] and nitrogen tetroxide [NTO]) for larger maneuvers. Two high-pressure helium tanks are also used to provide pressure for the bipropellant and monopropellant tanks. The spacecraft (i.e., the Orbiter, the Probe and its supporting equipment, and the launch vehicle adapter), with propellants, would weigh 5,824 kg (12,840 lb) at launch (JPL 1993a).

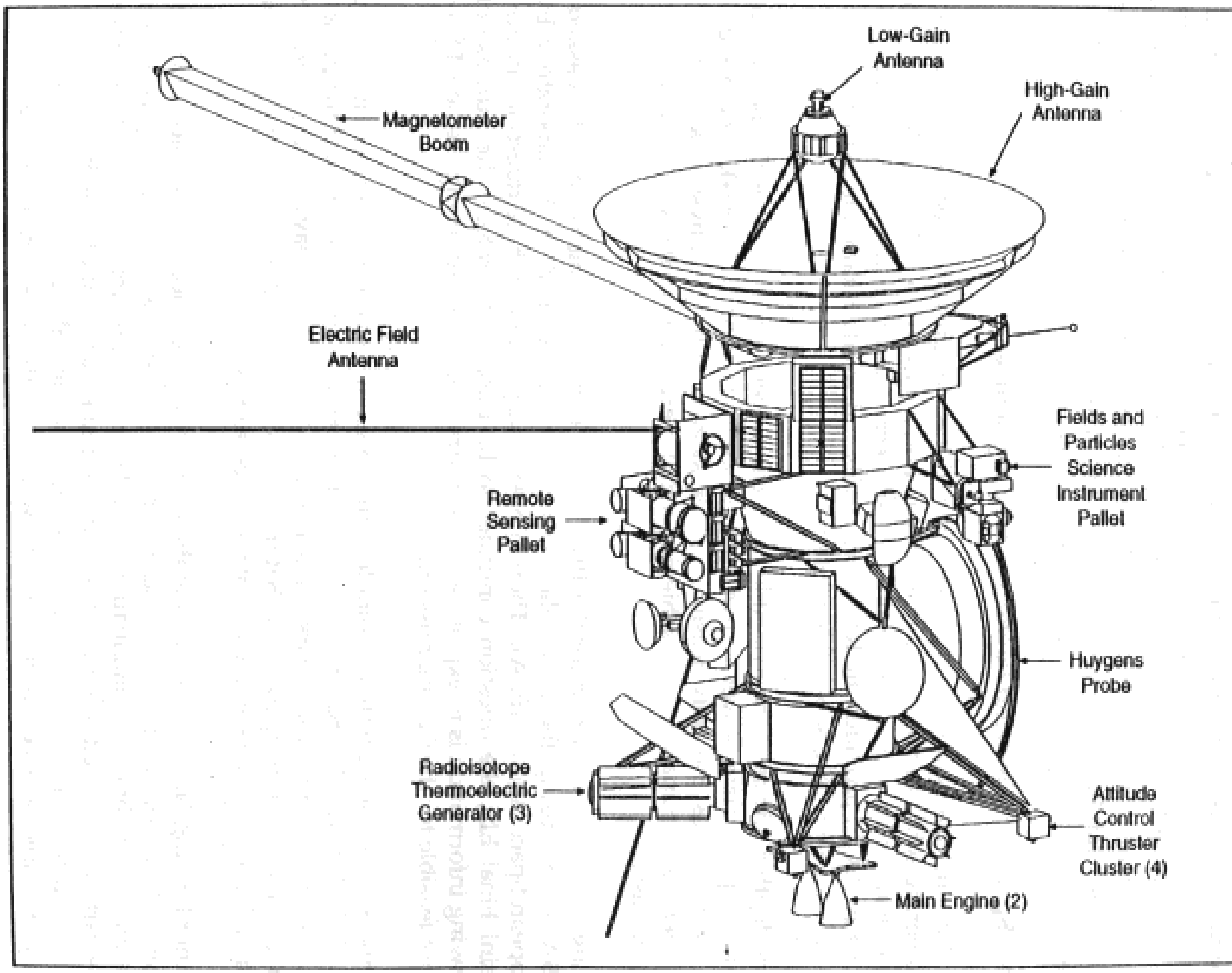

Figure 2-2 Diagram of the Cassini Spacecraft

Spacecraft Design Modifications Since the 1995 Cassini EIS: The spacecraft design has been modified in four places to improve the protection against micrometeoroid damage to the spacecraft propulsion subsystem. First, two layers of beta cloth (a woven fiberglass material more resistant to micrometeoroid damage than the multi-layer insulation material used for the spacecraft thermal blankets) were added to the core propulsion module. Second, stand-off beta cloth shields have been added around the helium and hydrazine tanks. Third, the thickness of the outer plate on the propulsion electrical box on the spacecraft bus was increased from 0.18 cm (0.070 in) to 0.89 cm (0.350 in). Fourth, a retractable main engine cover was added to protect the nozzles.

2.1.4 Spacecraft Electrical Power and Heating Sources

The Cassini spacecraft would use three RTGs to provide electrical power for its engineering subsystems and science payload and a maximum of 129 RHUs to regulate the temperature of various subsystems on the spacecraft and the Probe. The U.S. Department of Energy (DOE) provides the RTGs and RHUs and would retain title to them at all times. (See 1995 Cassini EIS Chapter 2 for details.)

An in-depth analysis of the available electrical power systems was performed to identify the most appropriate power source for the Cassini mission (JPL 1994). The use of RTGs was identified as the only feasible power system with the physical and operational characteristics compatible with achieving a high percentage of the science return from the Cassini mission.

During the comment period for the 1995 Draft Cassini EIS, some commentors asked why NASA is not using the new solar cells recently developed in the laboratory by the European Space Agency (ESA). Though NASA responded to these questions in the 1995 Cassini Final EIS, the question continues to be raised. Therefore, the purpose of the following information is to explain why solar arrays, even arrays using the new ESA cells, are not feasible for the Cassini mission.

For the Cassini spacecraft to complete the mission's science objectives, it must carry enough fuel to travel to Saturn, to brake and insert itself into orbit around the planet and to continue in orbit for four years. This amount of fuel is very heavy. Thus, in order to be light enough to launch, travel to Saturn and accomplish the science objectives of the mission, it is critical to keep the rest of the spacecraft as light as possible.

Another limiting factor in completing the mission science objectives is spacecraft electrical power. While orbiting Saturn and its moons, Cassini will use a variety of science instruments, singly or in combination, to collect many different types of data. Since the spacecraft has a limited amount of fuel and a limited amount of time in which to collect data at Saturn (four years), its power system must have the capability to simultaneously supply multiple science instruments, as well as continuously run the spacecraft itself.

Thus, a lightweight and highly-efficient method of providing electrical power becomes very important.

NASA has found that even with solar arrays containing the latest high-efficiency solar cells developed by ESA, it would not be possible to conduct the Cassini mission using solar power. The simplest and most immediate explanation for this is that the arrays, in order to meet Cassini's electrical power requirements, would have to be so large that the spacecraft as a whole would be too massive to launch.

ESA has produced, under laboratory conditions (i.e., not manufacturing conditions), highly-efficient solar cells that have been tested successfully under simulated space environments. These environments approximated the sunlight and temperature conditions at about 805 million kilometers (500 million miles) from the Sun, or about the same distance as Jupiter's orbit. These solar cells do not exhibit the typical low-intensity, low-temperature (LILT) degradation that considerably reduces efficiencies for currently-available commercial cells. However, it is important to note that the cells could be less efficient at Saturn, which is almost twice as far from the Sun as Jupiter. Figure 2-3 depicts the size of the theoretical arrays that would be required if a solar Cassini mission were possible.

Other limitations of the ESA solar cell technology include:

- The actual efficiencies of commercially-produced advanced solar cells have historically been somewhat lower than efficiencies reported for research and development (R&D) manufactured units.
- The ESA gallium arsenide (GaAs) devices are relatively thick and heavy compared to conventional solar cells.
- Considering theoretical analysis and published data, these advanced cells would be radiation sensitive. This would lower their efficiency if used on Cassini, due to the radiation environment through which the spacecraft will travel on its way to Saturn.
- If an array were to be made with the ESA cells (or any solar cells, for that matter), special diodes would have to be added to the array to compensate for cell fracturing that would be expected to occur from time to time. These diodes would add even more mass and complexity to the array.

Taking the previous data into consideration, the Jet Propulsion Laboratory (JPL) has estimated that solar arrays built for the Cassini mission would require a total area greater than 500 square meters (5,380 square feet) and that the spacecraft would require two arrays, each 9 meters (30 feet) wide and 32 meters (105 feet) long. There would also have to be supporting structures for the solar cells.

Attaching two such huge solar arrays to the Cassini spacecraft would severely impact the design, mass and operation of the spacecraft. One significant factor would be the array itself, which is a mechanical structure that ties the many solar cells together. This

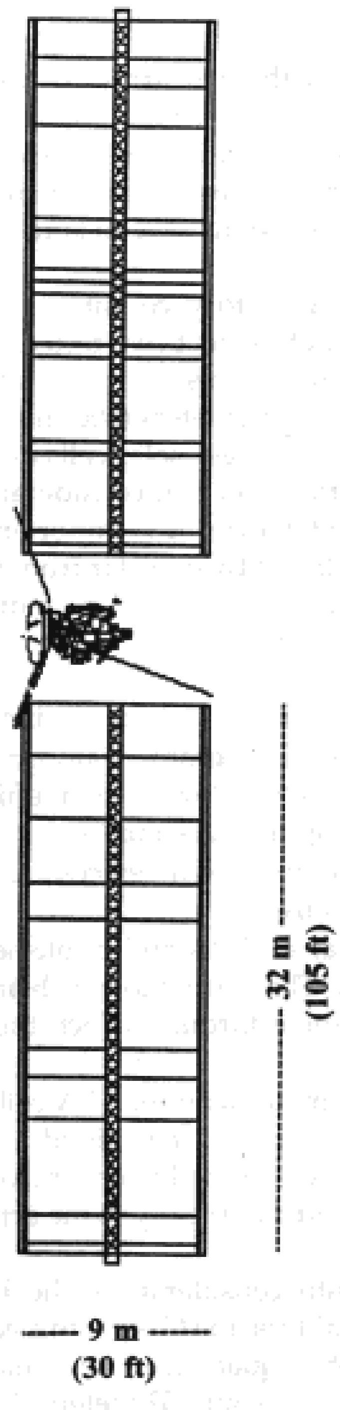

Figure 2-3 Theoretical Arrays (Using ESA GaAs Cells) for the Cassini Spacecraft

structure would have to be deployable, which means that it would have to be stowed for launch so that it could fit inside the Titan IV payload fairing and then unfold once the spacecraft was on its way to Saturn. This, in turn, would require mechanical components to fold and unfold the arrays and support the long array arms when extended. Such components and support structures would increase the size and mass of the spacecraft considerably. The long and unwieldy solar arrays would also severely complicate spacecraft maneuvering and turning for scientific observations and data transmission back to Earth. Therefore, special devices would have to be added to enable the spacecraft to turn, again adding significantly to the mass. Finally, to properly regulate electrical power on board the spacecraft, special regulators and batteries would be required. This, too, would increase the overall mass.

As with other solar power options studied for the Cassini spacecraft, the extremely large mass of even the lightest solar configuration is beyond the lift capability of the Titan IV (SRMU)/Centaur launch vehicle. Even if a heavy-lift booster and a suitable upper stage could be developed and certified for such a massive solar-powered spacecraft, the adjustments necessary to accommodate solar power would have substantial negative effects on the mission. First, they would make spacecraft maneuvering so slow and difficult that the mission would run out of time for scientific data collection, causing some crucial observations to be lost. Second, the addition of so many moving parts susceptible to mechanical failure would add considerably to the overall risk to mission success. As a final note, the researchers who developed the ESA solar cells evaluated the JPL solar study and concluded that "Low (insolation) intensity and low temperature (LILT) solar cells (including those developed by ESA) are not a viable power source alternative for the presently defined Cassini mission of NASA" (see Appendix C).

The present standard General Purpose Heat Source (GPHS) module is a product of years of extensive safety testing and analyses. Previous NASA spacecraft such as Galileo and Ulysses carried instruments powered by GPHS modules. Any future development of new GPHS modules would require extensive testing, evaluation, and space qualification before becoming potentially applicable to any space mission.

2.1.5 Spacecraft Propulsion Module Subsystem

The propulsive power for the Cassini spacecraft will be provided by two redundant bipropellant 445 N (105 lb of thrust) main engines for trajectory and orbit changes, and 16 monopropellant thrusters rated at 1.0 N (0.22 lb of thrust) for attitude control and very small orbit changes (JPL 1993c). The bipropellant engines use nitrogen tetroxide (NTO) and monomethyl hydrazine (MMH), and the monopropellant thrusters burn hydrazine. Pressures in both the bipropellant and monopropellant elements are maintained using helium gas.

2.1.6 Launch Vehicle (Titan IV [SRMU]/Centaur) Configuration

The Titan family of expendable launch vehicles has a launch history spanning more than 30 years of operations involving more than 320 Titan vehicles of all models. Titans have successfully carried astronauts into space ten times and have successfully launched RTG-powered spacecraft into space five times. The Titan IV/Centaur with the newly-developed SRMUs is proposed for this mission to Saturn. The SRMUs are now flight-certified and are the most capable strap-on U.S. boosters available.

The Titan IV/Centaur comprises four basic components: core vehicle, the solid rocket booster motors (upgrade) (SRMU), payload fairing (PLF) and Centaur (upper stage). The Titan IV (SRMU)/Centaur configuration is shown in Figure 2-4.

The core vehicle, which provides thrust, consists of two stages with their associated airframes, structures, avionics, mechanical systems and liquid propulsion system. Stage 1 contains two bipropellant liquid rocket engines. The oxidizer is 101,176 kg (223,051 lb) of NTO, and the fuel is 53,240 kg (117,372 lb) of Aerozine-50 (i.e., a 50-50 blend of unsymmetrical dimethylhydrazine and hydrazine). Stage 2 contains a single bipropellant engine virtually identical to the two used in Stage 1. The Stage 2 propellants comprise 22,239 kg (49,028 lb) of NTO and 12,436 kg (27,416 lb) of Aerozine-50 (Martin Marietta 1992).

Two SRMUs, located on opposites sides of the core vehicle, would provide the initial boost for the launch vehicle at liftoff. Each SRMU is composed of three solid rocket motor segments. The filament-wound motor segments consist of a graphite fiber/epoxy resin composite cased forward segment with an integral forward dome, two graphite/epoxy composite cylindrical sections and a steel aft dome. The SRMU has passed all of its qualification tests and is now flight-certified. The first mission using the SRMU was successfully launched by the USAF on February 23, 1997.

Each SRMU is 34.3 m (112.4 ft) long and has a 3.32 m (10.9 ft) outer diameter. The nominal weight for each SRMU is 352,271 kg (776,612 lb), of which 315,724 kg (696,040 lb) are propellant. The propellant is a U.S. Department of Defense (DOD) Hazards Class 1.3 (DOD 1992), solid propellant, consisting of 69 percent ammonium perchlorate (dizoxier) and 19 percent nonspherical aluminum (fuel), with 9.06 percent hydroxyl terminated polybutadiene (HTPB) binder. The remaining 2.94 percent includes bonding and curing agents (MMT 1992).

The PLF, mounted on top of the core vehicle, encases the Centaur (upper stage) and spacecraft, thereby providing aerodynamic and thermal protection for these elements during ascent. The payload fairing is an all-metal structure composed primarily of aluminum and has three segments. At approximately 206 seconds after liftoff, each of the

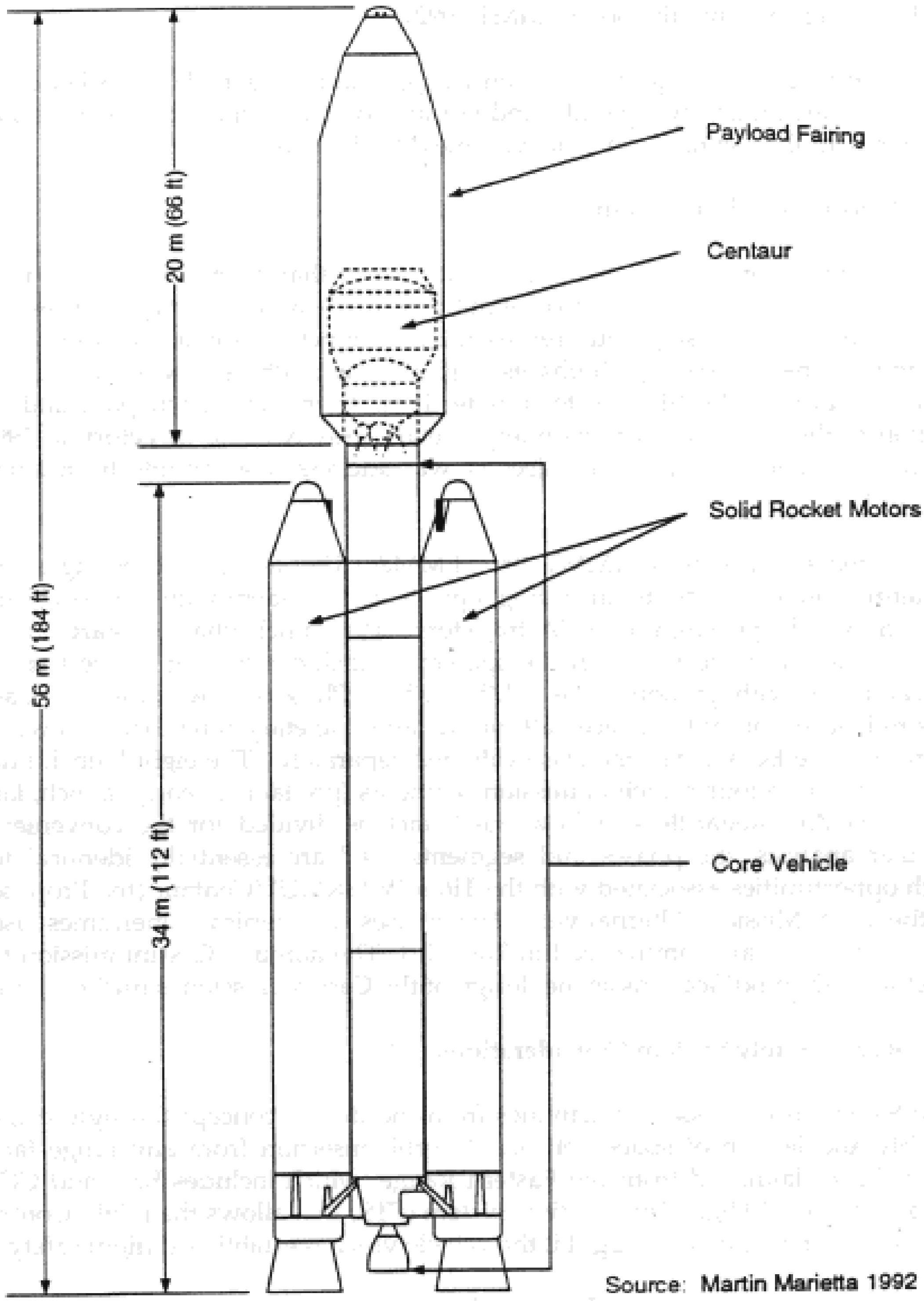

Figure 2-4 Diagram of the Titan IV (SRMU)/Centaur Launch Vehicle

three fairing segments would uncouple and be jettisoned from the rest of the launch vehicle, falling back into the ocean (MMT 1992).

The Centaur uses two liquid hydrogen (LH_2)/liquid oxygen (LO_2) rocket engines with multiple restart capability. The LH_2 and LO_2 are contained in two large tanks that account for the bulk of the Centaur's internal volume (MMT 1992).

2.1.7 Cassini Mission Timeline

The Cassini mission timeline is divided into phases that primarily serve as the basis for potential launch accident scenario definitions and environmental analyses. The 1995 Cassini EIS, in addressing four representative launch accident scenarios, divided the mission timeline into six launch phases, beginning with Phase 1, which commences at T-0 s, with ignition of the SRMUs to initiate liftoff from the launch pad, and ends with insertion of the spacecraft into its interplanetary gravity-assist trajectory in 1995 Cassini EIS Phase 6. The gravity-assist trajectory was addressed separately from launch of the spacecraft.

The updated safety analyses (MMT 1997, LMM&S 1997 a-j), in addressing a larger array of potential launch accidents (including a pre-launch accident with a release), divided the launch into eight phases, plus EGA trajectory. Pre-launch Phase 0, starts at T-48 hours with installation of the RTGs on the spacecraft, includes fueling of the Centaur upper stage, and ends with ignition of the SRMUs at T=0. Phase 8 (as with the 1995 Cassini EIS's Phase 6) is insertion of the spacecraft into its interplanetary trajectory. As with the 1995 Cassini EIS, the EGA trajectory was evaluated separately. The eight launch phases were also grouped into four principal mission segments (pre-launch, early launch, late launch, plus the EGA). Regardless of how the launch is divided for the convenience of the particular analysis, the phases and segments used are essentially identical for all the launch opportunities associated with the Titan IV (SRMU)/Centaur (the Proposed Action and the 2001 Mission Alternative). The phases and typical timeframes used in the ongoing analyses are summarized in Table 2-1. The nominal Cassini mission timeline is subject to slight modifications as the design of the Cassini mission is further refined.

2.1.8 Range Safety System Considerations

Range Safety encompasses all activities from the design concept through test, checkout, assembly and launch of space vehicles, to orbit insertion from any range facility. All space vehicles launched from the Eastern Range, which includes KSC and CCAS, must carry an approved Flight Termination System (FTS) that allows the Flight Control Officer (FCO) to terminate powered flight if the vehicle violates established flight safety criteria.

The FTS, which includes the Titan IV launch vehicle system and a Centaur system, provides ground personnel with the capability to shut down any thrusting liquid stage only, or to shut down any thrusting liquid stage and then destruct the SRMUs and all

Table 2-1. Cassini Mission Launch Segments and Phases and Key Events for the Updated Analyses

		Mission Elapsed Time, seconds		Phase Start and Finish Events
Mission Segment	**Phase**	**Phase Start**	**Phase Finish**	**Key Events in Phase**
Pre-Launch	0	-48 hours	0	**Complete RTG Installation (PLF Door Closure) to SRMU Ignition** Start Centaur Tanking; Complete Centaur Tanking; Arm Ordnance
Early Launch	1	0	143	**SRMU Ignition to SRMU Jettison** Clear Launch Complex; Clear Land; Reach 10 km Altitude; Safe SRMU and Centaur AutoDestruct Systems (ADSs); Stage 1 Ignition
	2	143	206	**SRMU Jettison to PLF Jettison** SRMU Separation System Fires
Late Launch	3	206	320	**PLF Jettison to Stage 1 Jettison** PLF Separation System Fires; Safe Stage 1 ADS; Stage 2 Ignition
	4	320	554	**Stage 1 Jettison to Stage 2 Jettison** Stage 1 Separation System Fires; Safe Stage 2 ADS
	5	554	707	**Stage 2 Jettison to Centaur Main Engine Cut-Off (MECO) 1** Stage 2 Separation System Fires; Centaur Main Engine Start (MES) 1; Attain Park Orbit
	6	707	1,889	**Centaur MECO 1 to Centaur MES 2** Safe Centaur Flight Termination System
	7	1,889	2,277	**Centaur MES 2 to Earth Escape**
EGA	8	2,277	2,349	**Earth Escape to Centaur MECO 2**
	Interplanetary trajectory/Earth swingby			

liquid stage tanks. This element of the FTS is called the command shutdown and destruct system (CSDS).

Additionally, the FTS will automatically destruct a stage that prematurely separates from the portion of the vehicle carrying the command receivers and antennas. This element is referred to as the automatic destruct system (ADS). Upon activation of an automatic destruct, Range Safety can, at their discretion, command destruct the Centaur and the remaining Titan IV elements.

The necessity for and design issues involved in a Space Vehicle Destruct System (SVDS) for the Cassini spacecraft were reviewed to determine if a SVDS would reduce the risk in the event of a launch phase accident. Analyses and testing involving the spacecraft's hypergolic propellant indicated that the launch vehicle configuration for the Proposed Action would not require a SVDS. (A SVDS is, therefore, not on the Cassini spacecraft.)

Range Safety System Modifications Since the 1995 Cassini EIS: Since publication of the EIS, two additional Range Safety systems have been added to improve the FCO's ability to monitor vehicle off-nominal turns. These systems include a Laser Illumination System (LIS) and Range Safety Advisory System (RSAS).

The LIS provides vehicle attitude imaging during nighttime launches and is used in conjunction with the RSAS to detect off-nominal turns early in the launch. The LIS consists of three portable equipment setups to provide at least two operational systems for launch. Vehicle attitude imaging during nighttime launches and/or conditions of fog are provided by laser pulses that reflect off the vehicle back to cameras near the launch site. The image is displayed at the FCO console in the Range Operation Control Center (ROCC), providing the primary tool for determination of launch vehicle attitude during the first 30 seconds of flight.

The RSAS assures minimization of FCO reaction time early in the launch, when attitude control failures could result in an intact impact of the full vehicle with the surface of the Earth (ground or hard surface). The RSAS uses vehicle telemetry, from the Titan IV core vehicle and the Centaur upper stage, to supplement the full complement of data (including LIS) used to monitor launch vehicle attitude. This provides early detection of conditions that could lead to an intact impact of the launch vehicle by providing an auditory advisory signal to the FCO when abort telemetry criteria is reached. Primary information from the LIS for a command destruct decision is considered confirmed when the RSAS auditory signal is heard.

The effect of the above changes is to increase the reliability of the FCO response in the unlikely event that a command destruct action would be required during the early phases of the Titan IV launch. This, in turn, keeps the probability of an intact impact of a complete launch vehicle very low.

2.2 DESCRIPTION OF THE 2001 MISSION ALTERNATIVE

The 2001 Mission Alternative would be similar to the Proposed Action in that it would include the Cassini spacecraft with the Huygens Probe and the Titan IV (SRMU)/Centaur launch vehicle, as described in Sections 2.1.3 through 2.1.5 of this SEIS. The primary launch opportunity for this mission alternative, however, would insert the Cassini spacecraft into a non-EGA trajectory. The launch vehicle would be the Titan IV (SRMU)/Centaur and would have a similar mission timeline as described in Section 2.1.7 of this SEIS. The primary launch opportunity would occur during the first 2.5 weeks of March 2001 , and would use a 10.3-year VVVGA trajectory, as depicted in Figure 2-5. The first Venus swingby would occur in August 2001, the second in September 2002, and the

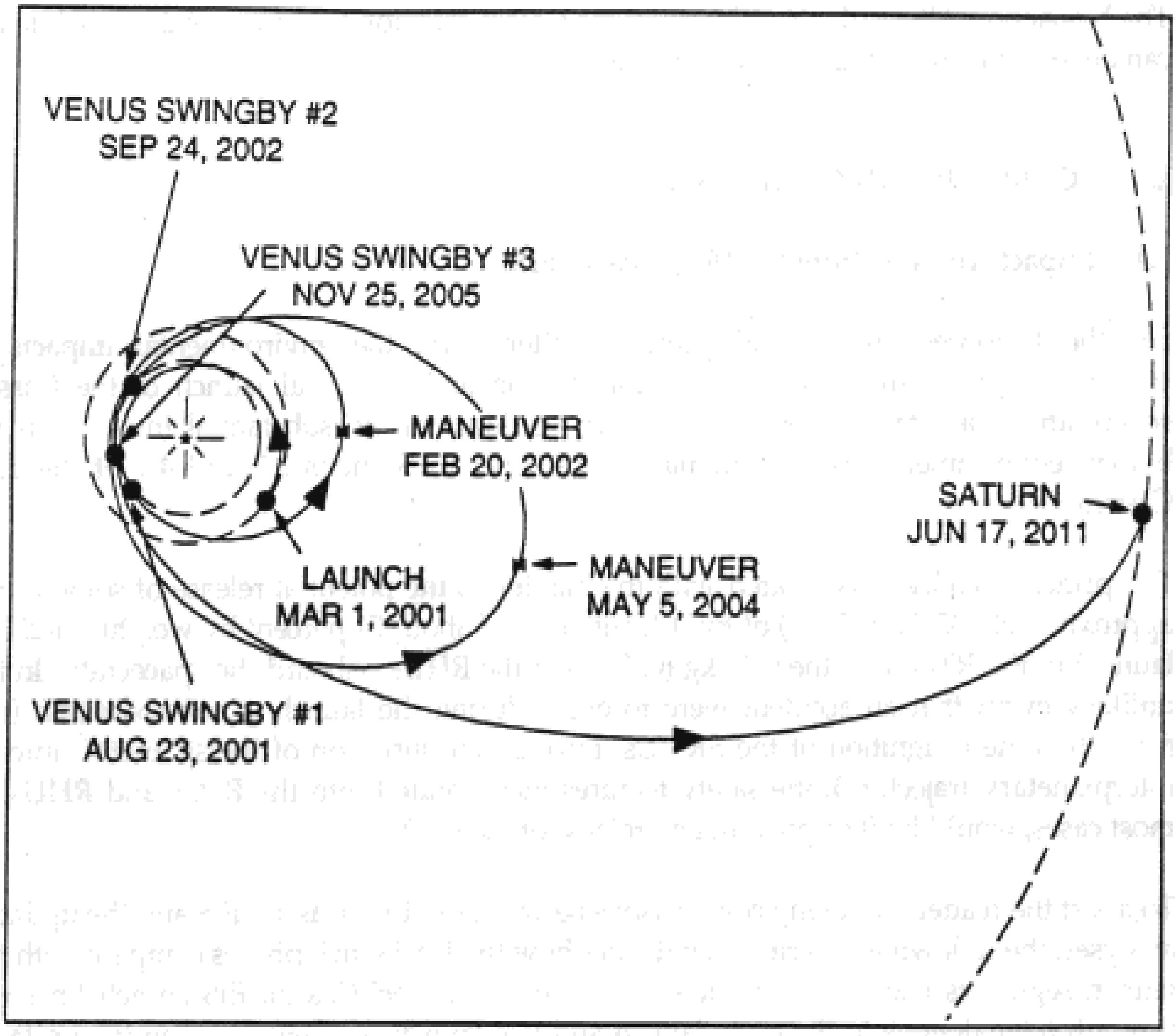

Figure 2-5 Cassini March 2001 VVVGA Interplanetary Trajectory

third in November 2005, with Cassini arriving at Saturn in June 2011 for the four-year tour of the Saturnian system (JPL 1994). A backup opportunity in May 2002 would use a VEEGA. This alternative was discussed in detail in Section 2.4 of the 1995 Cassini EIS.

2.3 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

The No-Action Alternative would cancel the Cassini mission to Saturn. Additional details can be found in Section 2.5 of the 1995 Cassini EIS.

2.4 COMPARISON OF ALTERNATIVES

2.4.1 Impact Analysis from the 1995 Cassini EIS

For the Proposed Action and preferred alternative, the environmental impacts of completing preparations for the Cassini mission and a normal launch of the Cassini spacecraft on a Titan IV (SRMU)/Centaur would entail no substantial impacts on the human environment. For additional details, refer to Sections 2.7 and 4.1 of the 1995 Cassini EIS.

The principal concern associated with the mission is the potential release of some of the approximately 32.7 kg (72 lb) of PuO_2 (consisting of about 71 percent by weight Pu-238 at launch) in the RTGs and the 0.35 kg (0.77 lb) in the RHUs onboard the spacecraft. In the unlikely event that an accident were to occur during the launch of the spacecraft (i.e., from the time of ignition of the SRMUs, through the insertion of the spacecraft into its interplanetary trajectory), the safety features incorporated into the RTGs and RHUs, in most cases, would limit or prevent any release of the PuO_2.

To assist the reader in making comparisons between the 1995 Cassini EIS and the updated analyses, the following description indicates how the EIS launch phases compare with the launch segments used in the updated analyses. For 1995 Cassini EIS launch Phases 1 through 6 (analogous to the early launch and late launch segments used in the updated analyses), four accident scenarios were identified in the 1995 Cassini EIS as representative of the categories of failures that could release PuO_2 to the environment. Pre-launch accidents were not covered in the EIS because, at that time, none were postulated that would result in a release of PuO_2. In addition, two postulated low-probability (i.e., much lower than the probabilities for Phases 1 through 6) accident scenarios that could occur during the interplanetary portions of the VVEJGA and VEEGA trajectories were identified as the short-term (EGA) and long-term inadvertent reentry scenarios. The short-term scenario would involve the inadvertent reentry of the spacecraft into the Earth's atmosphere during a planned Earth swingby, and the long-term scenario would involve a spacecraft failure that leaves the spacecraft drifting in an Earth-crossing orbit and potentially reentering the Earth's atmosphere a decade to millennia later.

The 1995 Cassini EIS analyses indicated that, depending on the accident scenario, the CCAS/KSC regional area, limited portions of Africa for an 8-10 second period under the space vehicle flight path, or indeterminate locations within the global area could be impacted by PuO_2 releases. The CCAS/KSC regional area could be impacted if an early Phase 1 (early launch segment in the updated analyses) accident were to result in a release. Areas outside the region (i.e., a portion of the African continent; areas elsewhere around the world) could be impacted if an accident resulting in a release were to occur in Phase 5 or 6 (late launch segment in the updated analyses). No releases of plutonium from the RTGs or RHUs to the environment were postulated in the 1995 Cassini EIS if any of the representative accident scenarios occurred in Phases 2, 3, or 4.

During the interplanetary portions of the mission, postulated short-term (EGA segment of the updated analyses) and long-term inadvertent reentry accident scenarios could result in releases of PuO_2 to the environment. However, NASA is designing the mission to greatly reduce the potential for such accidents. Mission design criteria require that the mean probability of an inadvertent reentry during the VVEJGA trajectory be no greater than one in a million. If such an accident were to occur, PuO_2 could be released in the upper atmosphere and/or scattered on indeterminate locations on the Earth's surface, resulting in a slight increase in the background radiological exposure of a large number of people worldwide.

The principal measure used in the Galileo and Ulysses Tier 2 EISs, and in the 1995 Cassini EIS and supporting safety analyses, for characterizing the radiological impacts of each alternative evaluated, is health effects risk. Health effects are expressed as the number of excess latent cancer fatalities over a 50-year period (above the normally observed cancer fatalities). As used here, health effects mission risk is the probability of an accident resulting in a PuO_2 release (i.e., the probability of an initiating accident times the probability that the accident would result in a release of PuO_2), multiplied by the consequences of that accident (i.e., the 50-year health effects that could be caused by the exposure of individuals to the PuO_2), summed over all postulated accidents. Estimates of health effects mission risk, as discussed here, represent the expectation of latent cancer fatalities. The expectation health effects mission risk over all mission phases (i.e., the 50-year period health effects) does not include contributions to risk from the long-term EGA reentry scenario.

For the Proposed Action, the 1995 Cassini EIS mission risk estimate, considering all launch phases for the primary launch opportunity, was 8.4×10^{-7} (0.00000084) health effects. The mission risk from the short-term inadvertent reentry accident during the Earth swingby portion of the primary launch opportunity's VVEJGA trajectory was estimated as 1.7×10^{-3}, (0.0017) health effects, and for the secondary and backup opportunity VEEGA trajectories as 1.8×10^{-3} (0.0018) health effects. The overall mission risk (considering all launch phases and the EGA trajectories), from the primary launch opportunity was $1.7x10^{-3}$ (0.0017) health effects, and from the backup launch opportunity, it was estimated at $1.8x10^{-3}$ (0.0018) health effects.

2.4.2 Changes in Estimated Impacts from Accidents Since the 1995 Cassini EIS

The refinements in the evaluation of accidents and estimates of their potential consequences since the early scoping analysis of the Cassini EIS have resulted in different estimates of impacts. The following highlights the changes in approach for estimating the accident probabilities, health effects and risks:

- The EIS used four representative accidents for the launch of the mission and estimated their probabilities of occurrence. Pre-launch accidents were not addressed in the 1995 Cassini EIS because, at that time, none were postulated that would result in a release of PuO_2.

  The updated analyses use more detailed accident descriptions, accident environments and probability distributions. In addition, the updated mission safety analyses have determined that a release could occur from some on-pad accidents during the two hour period prior to launch. Further, the probabilities of accidental reentries during the late launch segment are higher than in the 1995 Cassini EIS.

- Both the 1995 Cassini EIS and the updated analyses use the same accident definition and event trees for the inadvertent reentry during an Earth swingby accident. The 1995 Cassini EIS reported bounding estimates of potential releases because there was uncertainty in whether the General Purpose Heat Source (GPHS) modules or Graphite Impact Shells (GISs) would survive an inadvertent reentry during Earth swingby or release plutonium in the upper atmosphere.

  The updated analyses uses results of additional research and modeling to refine estimates of behavior of RTGs, GPHS modules and components on reentry. The analysis also uses probability distributions for some key variables on the reentry event trees used in the 1995 Cassini EIS rather than nominal estimates of the branch probabilities. The results are reported as probability distributions of source terms for the accident.

- The 1995 Cassini EIS used simpler techniques to estimate nominal and maximum source terms and the corresponding conditional probabilities that PuO_2 would be released.

The updated analyses use probabilistic techniques to evaluate the accident conditions. The resultant source terms are reported as a probability distribution for each accident case.

- The 1995 Cassini EIS modeled accident consequences using the same basic approaches, assumptions and model parameters that had been used for the Galileo and Ulysses missions.

  The updated analyses extends techniques used in the 1995 Cassini EIS and for the Galileo and Ulysses missions. The analysis makes wide-scale use of probability distributions. It uses best estimate values for certain key parameters, and more comprehensive modeling to determine PuO_2 particle dispersion, uptake by people and the potential for latent cancer fatalities. (Best estimates are defined in Appendix B.)

- The 1995 Cassini EIS stated that there were uncertainties in the estimated probabilities of an accident occurring, the conditional probabilities of material being released and the resultant source terms of the accidents.

  The updated analyses include the most extensive evaluation of the uncertainties of accident consequences ever attempted for a space mission. The analysis expands techniques reported for the Ulysses mission and provides an estimate of the consequences and risk with their associated uncertainties.

Launch phase consequence and risk estimates from the updated analyses are derived directly from a mathematical distribution as opposed to the 1995 Cassini EIS's point estimates that were based on a semi-quantitative assessment of previous mission safety analyses. A comparison of the two sets of estimates indicates that the 1995 Cassini EIS's overall assessment of risk was close to results of the updated analyses, even though the 1995 Cassini EIS's assessment of individual mission risk and variability were lower for launch phase accidents, but higher for the EGA swingby accident risk. Both the 1995 Cassini EIS and the updated analyses indicate that only a fraction of conceivable launch accidents could result in releases of PuO_2.

2.4.3 Overview of Updated Mission Safety Analyses of Radiological Impacts from Accidents

Since completion of the Final EIS for the Cassini Mission (dated June 1995) NASA and DOE have continued the safety analysis process for the mission. This process was described in Section 4.1.5.1 of the 1995 Cassini EIS. The "Cassini Titan IV/Centaur RTG Safety Databook, Revision B" dated March 1997 (MMT 1997), describes accident probabilities and environments for the mission. DOE contractors have incorporated the MMT 1997 information into their accident analyses and recently completed their preparation of the Safety Analysis Report (SAR) "GPHS-RTGs in Support of the Cassini

Mission" (LMM&S a-j). Results from those analyses, along with the companion SAR for the LWRHUs (EG&G 1997), are reported in this SEIS. While some of the individual results of the SARs differ from those reported in the April 1997 Draft SEIS and companion document HNUS 1997, the overall mission risk remains similar.

Concurrent with the recent completion of the SAR (LMM&S a-j), a supplement to the Cassini Earth Swingby Plan dated May 19, 1997 (JPL 1997) was issued. This supplement contains slightly lower estimates of EGA inadvertent reentry probabilities, and is part of the separate, (non-NEPA), ongoing nuclear launch safety analysis process and will be evaluated as a part of that process.

The process currently used by the updated mission safety analyses in determining the mission risk associated with the Cassini mission is similar to the process used for the earlier Galileo and Ulysses missions. The PuO_2 release potentially resulting from each accident (i.e., the source terms) are determined by evaluating the response of the RTGs and RHUs to the defined accident environments. For each combination of accident and environment, simulations are used to determine the probability of rupture or breach of the iridium clads of the RTGs or the platinum-rhodium clads of the RHUs, which contain the PuO_2. For simulations in which clad failure occurs, the mass of the PuO_2 escaping the clad is determined, along with information on particle size, particle density and release location. The safety analyses for both the RTGs and RHUs utilized empirical results of safety tests and analyses, and modeling studies conducted by DOE and NASA. The updated analyses, however, are more refined and comprehensive than those used for the 1995 Cassini EIS.

Table 2-2 presents the means of the best estimate results from the updated analyses, and compares them with the results in the 1995 Cassini EIS. (See Appendix B for a description of the best estimate.) The launch accidents and consequences addressed here apply to both the Proposed Action and 2001 Mission Alternative.

Pre-launch accidents were not addressed in the 1995 Cassini EIS because at that time none were postulated that would result in a release of PuO_2. Since that time, updated analysis has shown that PuO_2 releases could result at the launch pad if the Centaur upper stage experienced a major structural or mechanical failure during the two-hour pre-launch fueling and preparation period. The probability of a pre-launch accident that could result in a release of PuO_2 is $5.2x10^{-5}$, or 1 in 19,200, and could result in 0.11 health effects and could contaminate 1.5 km^2 (0.58 mi^2) of land above $7.4x10^3$ Bq/m^2 (0.2 $\mu Ci/m^2$) (the EPA's guideline level for considering the need for further action, EPA 1990). Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 1.0 or more health effects could occur. The total probability of such an accident is $5.2x10^{-7}$, approximately 1 in 1.92 million. Land area contaminated above the EPA guideline level could exceed 8.6 km^2 (3.3 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

Table 2-2. Comparison of Updated Mean Estimates of Accident Parameters with the 1995 Cassini EIS

Mission Segment	Document	Total Probability[a]	Maximum Individual Dose[b], rem	Land Area Contaminated[c], km^2	Health Effects[d] (w/o *de minimis*)	Mission Risks[e]
Pre-Launch	SEIS	$5.2x10^{-5}$	$1.4x10^{-2}$	$1.5x10^{0}$	$1.1x10^{-1}$	$5.5x10^{-6}$
	EIS	f	f	f	f	f
Early Launch	SEIS	$6.7x10^{-4}$	$2.1x10^{-2}$	$1.6x10^{0}$	$8.2x10^{-2}$	$5.5x10^{-5}$
	EIS	$1.1x10^{-3}$	$5.8x10^{-5}$	$8.8x10^{-2}$	$4.1x10^{-4}$	$4.6x10^{-7}$
Late Launch	SEIS	$2.1x10^{-3}$	$1.1x10^{0}$	$5.7x10^{-2}$	$4.4x10^{-2}$	$9.2x10^{-5}$
	EIS	$9.4x10^{-4}$	$3.2x10^{-2}$	$8.4x10^{-3}$	$3.9x10^{-4}$	$3.7x10^{-7}$
VVEJGA	SEIS	$8.0x10^{-7}$	$5.1x10^{2}$	$1.5x10^{1}$	$1.2x10^{2}$	$9.8x10^{-5}$
	EIS	$7.6x10^{-7}$	$3.1x10^{1}$	$2.0x10^{-3}$	$2.3x10^{3}$	$1.7x10^{-3}$
Overall Mission	SEIS	$2.8x10^{-3}$	$9.7x10^{-1}$	$4.5x10^{-1}$	$8.9x10^{-2}$	$2.5x10^{-4}$
	EIS	$2.1x10^{-3}$	$2.6x10^{-2}$	$7.8x10^{-1}$	$8.3x10^{-1}$	$1.7x10^{-3}$

a. Product of initating accident x conditional PuO_2 release probabilities.
b. Maximally exposed individual dose.
c. Land area potentially contaminated above $7.4x10^3$ Bq/m^2 ($0.2\ \mu Ci/m^2$).
d. Health effects are incremental latent cancer fatalities.
e. Risk calculated as the total probability times health effects.
f. No pre-launch accidents resulting in a release were postulated in the EIS.

While the probability of an early launch accident that could threaten the RTGs is $6.2x10^{-3}$, or 1 in 160, the probability of an early launch accident that could result in a release of PuO_2 is $6.7x10^{-4}$, or 1 in 1,490, and could result in 0.082 health effects and could contaminate 1.6 km^2 (0.62 mi^2) of land above the EPA guideline level. Such an accident could occur in a number of ways, such as, if the RTGs impacted ground on or near the launch pad following an in-air explosion due to a malfunction, or by the activation of the CSDS or ADS. In comparison to the 1995 Cassini EIS, this mission segment's mean mission risk is $5.5x10^{-5}$ (0.000055) health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000046. Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 1.5 or more health effects could occur. The total probability of such an accident is $6.7x10^{-6}$, less than 1 in 149,000. Land area contaminated above the EPA guideline level could exceed 20 km^2 (7.7 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

While the probability of a late launch accident is $2.1x10^{-2}$, or 1 in 48, the probability of an accident that results in a release of plutonium is $2.1x10^{-3}$, or 1 in 476, and could result in 0.044 health effects and could contaminate 0.057 km^2 (0.02 mi^2) of land above the EPA guideline level. Such accidents could occur if a Centaur failure resulted in atmospheric reentry and hard surface impact of the RTG modules. For suborbital accidents, a hard surface impact on southern Africa and/or Madagascar is only possible during a ten-second window of the suborbital flight. Orbital failures leading to ground impact could occur after attaining park orbit and result in orbital decay reentries from minutes to years after the initial accident if implementation of the spacecraft's Sufficiently High Orbit (SHO) capability failed. (In the event of a late launch accident, such as a failure of the Centaur upper stage to initiate its second burn and send the spacecraft on its interplanetary trajectory, the spacecraft has a capability to be separated and boosted to a high [2000+ year] storage orbit.) For those late launch Centaur accidents, for which the spacecraft cannot be successfully separated and boosted, orbital decay reentries would occur from minutes to years after the accident. In comparison to the 1995 Cassini EIS, this mission segment's mean mission risk is $9.2x10^{-5}$ (0.000092) health effects, which exceeds the EIS estimate of 0.00000037. Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 0.55 or more health effects could occur. The total probability of such an accident is $2.1x10^{-5}$, or less than 1 in 47,600. Land area contaminated above the EPA guideline level could exceed 0.34 km^2 (0.13 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

The probability of an EGA accident that results in a release of plutonium is $8.0x10^{-7}$ or less than 1 in 1 million, and could result in 120 health effects and could contaminate 15 km^2 (5.8 mi^2) of land above the EPA guideline level. Such an accident could occur if, during the EGA swingby, the Cassini spacecraft became non-commandable after experiencing a failure that placed it on an Earth impact trajectory and subsequently released PuO_2 at high altitude or as a result of ground impacts. In comparison to the 1995 Cassini EIS, this mission segment's mean mission risk is 9.8×10^{-5} (0.000098) health effects, which is less than the 1995 Cassini EIS estimate of 0.0017. Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 450 or more health effects could occur. The total probability of such an accident is 8.0×10^{-9}, approximately 1 in 125 million. Land area contaminated above the EPA guideline level could exceed 55 km^2 (21 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

As noted earlier, if the spacecraft were to become non-commandable during its interplanetary trajectory, and control could not be restored, its orbit around the Sun could intersect that of the Earth resulting in a long-term inadvertent reentry. The probability of such an event is 2.0×10^{-7} or, 1 in 5 million. It is reasonable to assume that the consequences of such a reentry would be of a similar order of magnitude as that estimated for the short-term EGA.

In addition to the above best estimate analyses, DOE has conducted a study of the uncertainty in the underlying test data and models used to estimate accident risks and consequences. This information is presented in Chapter 4 of this SEIS; see also HNUS 1997 and Appendix D.

2.4.4 2001 Mission Alternative

With respect to the 2001 Mission Alternative, which would also be launched on a Titan IV (SRMU)/Centaur, the 1995 Cassini EIS concluded that potential launch accident consequences and risks would be essentially the same as those estimated for the Proposed Action. This also holds for the updated results from the ongoing mission safety analyses. Specifically, the pre-launch, early launch and late launch consequence and risk analyses results would also apply to those segments of the 2001 Mission.

The only difference postulated at this time is in the EGA results, which do not apply to this alternative. Without an Earth swingby as part of its primary opportunity VVVGA trajectory, the probability of an inadvertent reentry accident during an Earth swingby would be zero. Therefore, radiological consequences associated with the Earth swingby would be eliminated. The backup opportunity for this alternative is a VEEGA, however, and therefore the potential exists for a short-term and a long-term inadvertent reentry as noted earlier for the Proposed Action. The potential consequences for the backup and the long-term accident are assumed similar to those postulated respectively for the secondary/backup and the short-term EGA accident described for the Proposed Action.

2.4.5 No-Action Alternative

The No-Action Alternative would not result in any adverse health or environmental impacts. For other impacts associated with the Non-Action alternative see Section 4.4 of the 1995 Cassini EIS, and Section 4.3 of this SEIS.

2.4.6 Summary Comparison of Alternatives

Table 2-3 provides a summary comparison of the Proposed Action, including the secondary and backup launch opportunities, and the alternatives. The factors used are the key parameters discussed in more detail in Chapter 4 of this SEIS and the 1995 Cassini EIS. All launch opportunities involve the Titan IV(SRMU)/ Centaur and are expected to have similar environmental impacts with normal launches. The accident impacts and risks are expected to be similar for the pre-launch, early-launch, and late-launch segments of each mission alternative with any of the launch opportunities. The principal differences involve the short- and long-term risks of an inadvertent reentry during the EGA and interplanetary cruise portions of the mission. Updated analyses indicate that the EGA accident impacts and risks are now estimated to be less than those presented in the 1995 Cassini EIS. As a result the mission risk contributions of each inadvertent reentry would be nominally the same.

Although the primary opportunity for the the 2001 Alternative uses a VVVGA trajectory and therefore presents no short-term inadvertent reentry risk, a long-term risk of an inadvertent reentry similar to the other launch opportunities would remain. The risks associated with the backup opportunity (a VEEGA trajectory) would be the same as the secondary and backup VEEGA opportunities for the Proposed Action.

Table 2-3 Summary Comparison of the Potential Mean Radiological Impacts and Risks for Cassini Mission Alternatives

Mission Segment	Proposed Action		2001 Alternatives		No-Action
	Primary (VVEJGA)	**Secondary/ Backup (VEEGA)**	**Primary VVVGA**	**Backup VEEGA**	
Pre-Launch					
Total Probability[a]	1 in 19,200	Same	Same	Same	No Effect
Health Effects	0.11	Same	Same	Same	No Effect
Land Area Contaminated (km^2)	1.5	Same	Same	Same	No Effect
Health Effects Risk	5.5×10^{-6}	Same	Same	Same	No Effect
Early-Launch					
Total Probability[a]	1 in 1490	Same	Same	Same	No Effect
Health Effects	0.082	Same	Same	Same	No Effect
Land Area Contaminated (km^2)	1.6	Same	Same	Same	No Effect
Health Effects Risk	5.5×10^{-5}	Same	Same	Same	No Effect
Late-Launch					
Total Probability[a]	1 in 476	Same	Same	Same	No Effect
Health Effects	0.044	Same	Same	Same	No Effect
Land Area Contaminated (km^2)	0.057	Same	Same	Same	No Effect
Health Effects Risk	9.2×10^{-5}	Same	Same	Same	No Effect
EGA/Interplanetary Cruise **• Short-Term Inadvertent Reenetry**					
Total Probability[a]	1 in 1,250,000	1 in 2,900,000	No Short Term	Same as Sec.	No Effect
Health Effects	120	227	None	Same as Sec.	No Effect
Land Area Contaminated (km^2)	15	21	None	Same as Sec.	No Effect
Health Effects Risk	9.8×10^{-5}	7.6×10^{-5}	None	Same as Sec.	No Effect
• Long-Term Inadvertent Reenetry					
Total Probability[a]	1 in 5,000,000	1 in 1,700,000	Same	Same as Sec.	No Effect
Radiological Impacts	similar to short-term	similar to short-term	Same	Same as Sec.	No Effect
Overall Mission Risk	2.5×10^{-4}	2.3×10^{-4}	Same	Same as Sec.	No Effect

a. Total probability of an accident with a release of PuO_2

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